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Approaches to an Improved IV and QE Characterization of Bifacial Silicon Solar Cells and the Prediction of their Module Performance

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Abstract

Being interested in bifacial and not fully covered rear contact (e. g. back contact) silicon solar cells and their rear side importance, we have studied how the sample holders add an external current mainly due to the reflectance properties of their surface and we have found that this influence can be higher than one percent in J_{SC}. In a second approach, an innovative measurement setup configuration is presented, which includes a simultaneous front-rear illumination. For this configuration we have measured two types of bifacial solar cells which can be distinguished by their ratio of front to rear performance and we have found differences in power output of about thirty percent if the rear illumination is applied or not. Modules with different back sheets were further manufactured using these types of bifacial solar cells. Outdoor measurements for modules with transparent back sheets demonstrated an average gain in power output of up to twenty percent if the module was placed on a highly reflecting surface and scattered light penetrated the module from the rear side. A set of mini modules was also tested indoors to show how the back sheet influences the reflection as well as the spectral resolved response of the devices.

Keywords: Characterization, Bifacial, Module

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1. Introduction

To assure the return of the warranted annual yield of photovoltaic outdoor installations along with the cost-saving potential of reduced tolerance specifications of photovoltaic modules, cell and module manufacturers worldwide pursuit an in-depth understanding of measurement procedures to minimize their uncertainties and gather benefit of accurate performance predictions. Current-voltage (IV) ratings and spectral quantum efficiencies (QEs), representing the most important characteristics of a readily fabricated solar cell or module, are of special interest within this approach.

Bifacial and not fully covered rear contact solar cells present difficulties when measured due to their bilateral properties and hence external contributions from the measurement systems itself. One approach to eliminate these contributions from the rear side would be to measure these devices on a setup and especially sample holder with a non reflective surface [1]. The resulting measurement would give an absolute value for a one side illuminated bifacial device but because of a lack of appropriate non reflective but in the same time conducting surface materials the technical implementation is challenging and causes difficulties.

From this starting point an alternative for steady illumination configuration was found by using an IV flasher. These measurements are widely used in industry, mainly because they give a quick classification of the solar cell performance. In our approach investigations showed additionally the potential to reduce rear side reflective effects. Moreover, technical modifications for this setup allow dosed light penetration from the rear what offers the possibility to measure the solar cell in a bifacial mode [2].

2. The measurement problem

We present an investigation of IV- and QE characteristics of bifacial silicon solar cells and mini-modules in contrast to their standard one sided industrial screen-printed complements. The impact of different sample holder materials and configurations as well as several back sheets is studied. This impact was quantified and a solution is proposed. We present a comprehensive study on this topic covering various sample stages as well as cell design - module back sheet combinations.

In this study we used bifacial solar cells with 55 Ω/sq phosphorous emitter and 60 Ω/sq B-diffused back surface field based on p-type substrates of a resistivity of 1.5 Ohm cm, leading a n^+pp^+ non-symmetric structure [3].

Our investigation presents alternative measurement set-ups for bifacial and not fully covered rear contact devices e. g. IBC cells. Moreover, it includes the performance prediction of encapsulated bifacial solar cells in arranged modules with back sheets and glasses of different characteristics and the design of high yield photovoltaic outdoor systems.

Another approach is presented in this work consisting in the simultaneous illumination of the both sides of the cell, in an attempt to simulate the actual working conditions of the solar cell in the bifacial mode. This approach is presented as an alternative to correct the impact of sample holders and offers a new measurement possibility.

Bifacial solar cells are employed in double- sided transparent modules, taking advantage of the natural albedo from the place where they are mounted in order to increase their power output. It is also possible to laminate these cells in a module with a high reflecting, and hence non-transparent back sheet to get the rear contribution on a constant but compared to monofacial solar cells elevated level. Different back sheets have been tested in mini modules, investigating the IV and QE characteristics in every case.

3. Results

3.1. IV for different sample holders

A set of rear total-BSF bifacial and standard industrial monofacial silicon solar cells has been chosen for IV characterization. Their transmission properties have been previously measured.

Different surfaces and back sheets have been also characterized with respect to their properties of reflection, absorption and transmission. The reflection values have been integrated over 300-1200 nm and they are shown in the Table I.

Previous results [1] show that the back reflectivity and the contact configuration of the sample holders influence the generated current and the fill factor. Nevertheless, this influence considers the effective reflection of the system cell-chuck, which is given by the light passing through the cell, reflected on the chuck surface and coming back into the rear side of the cell. For this calculation it is necessary to consider the transmission of the cell and the reflection of the chuck surface along the light spectrum.

To test this, a long term stabilized bifacial solar cell was measured in a flash solar simulator, maintaining the contact configuration and altering the optical properties of the chuck surface where the cell is placed. The following table shows the average results of these measurements, including short circuit current density variations compared to the standard chuck of the flasher.

TABLE 1. Bifacial cell measured on different chuck surfaces.

Type of chuck surface	*V_{oc} (mV)*	*J_{sc} (mA/cm^2)*	*FF (%)*	*η (%)*	*Rel. variation J_{sc} (%)*
Standard flasher chuck	622.69	36.75	75.08	17.18	N/A
Chuck 7% reflecting	622.82	36.61	75.08	17.12	-0.38
Chuck 72% reflecting	623.27	37.06	74.98	17.32	+0.84
Chuck 78% reflecting	623.17	37.05	74.88	17.29	+0.82
Chuck 85% reflecting	623.27	37.12	74.90	17.33	+1.01

The rear side of this cell was also measured, showing the same variation range for the low reflecting back sheet and over +1% in J_{SC} variation for the high reflecting back sheets [1].

3.2. IV and QE for mini modules

We have manufactured mini-modules representing one laminated solar cell using different back sheets (Fig 1.b). The reflecting surfaces and back sheets have been previously characterized with respect to their reflection properties, absorption and transmission. Fig. 1.a present the spectral response of a central 2x2 cm^2 spot of the bifacial cell before and after lamination and for a back sheet with low reflectance. It was found that the short wavelengths are absorbed in the range of 300-400 nm by the glass and EVA of the module covering the initial solar cell on the front side. The low reflecting back sheet absorbs a large part of the long wavelengths that pass through the solar cell without contributing to the generation of electron hole pairs in the bulk. Instead of optical reflection back into the device the back sheet absorbs this light and therefore the quantum response is decreased in the long wavelength range (from 900-1200 nm).

On the other hand, if the back sheet is high reflecting it increases the initial measured value almost along the whole range of wavelengths.

For this experiment solar cells were used providing almost the same efficiency if operated with the pn junction on the front or on the rear side of the device. An extension of the study to solar cells with different ratios of front to rear performance is already planned.

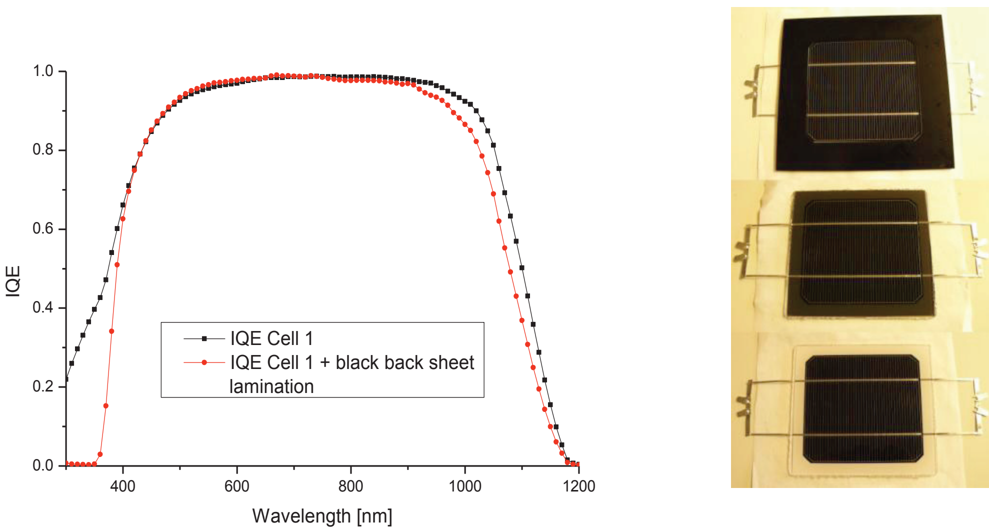

Fig. 1 a) Spectral response of bifacial solar cell before and after lamination with a black back-sheet of lowest reflectance. The glass encapsulation cuts short wavelengths and the low reflective back sheet reduces the initial measured values (done in a brass chuck). b) Mini modules of bifacial solar cells with different back sheets.

3.3. IV for both sides illumination

In another approach we allowed light penetrating the cell from the front and the rear side simultaneously [2], using two different light sources. The rear light source was calibrated to provide steadily 25% or 30% of one sun and the front light source gives the commonly used 1 sun flasher light for standard measurements. One bifacial cell was measured several times, first the front side with front side illumination only and afterwards simultaneously front plus 25% or 30% rear illumination. The procedure was repeated for the solar cell upside down and the results are presented in table 2.

TABLE 2. Bifacial cell measured at simultaneous light configurations.

Type of illumination	V_{oc} (mV)	J_{sc} (mA/cm^2)	*FF* (%)	P_{mpp} (W)	*Rel. variation* P_{mpp} (%)
Front side 1 sun, 0% rear	627.9	36.7	75.6	2.7	N/A
Front side 1 sun, 25% rear	625.5	44.1	74.9	3.2	19
Front side 1 sun, 30% rear	622.9	48.7	73.9	3.5	30
Rear side 1 sun, 0% front	616.5	26.2	76.0	1.9	N/A
Rear side 1 sun, 25% front	616.6	35.1	74.7	2.5	32
Rear side 1 sun, 30% front	614.0	38.9	73.4	2.7	42

When illuminating the cell from the back the representative improved parameter is J_{sc}. Although there is a drop in Voc and FF we observe an improved efficiency, depending on the amount of light coming from the rear side of the cell. This indicates that the ratio of performance of front to rear side of the cell has a strong effect on the results detected for simultaneous measurements which is in good accordance with observations for outdoor tests on module level.

As mentioned above the solar cells we use for these measurements have a non symmetric n^+pp^+ structure [3] and for this reason, there is a significant difference, if the device is operating in front or rear mode. It is also important to consider that the light sources used are not equal and this is other factor that can affect the solar cell performance.

Nevertheless, if we would like to extend this study for a standard test condition measurement of bifacial solar cells, other types of bifacial solar cell structure must be considered and this complicates the characterization for this type of cell devices. Therefore, we would like to remark that this method is a quick and convenient alternative for classification of bifacial solar cells since it describes the real operating mode of the cells. No other measurements upside down are needed and it can be extended to other types of bifacial cell configurations.

3.4. Transparent module, albedo collection

Outdoor measurements were made with a glass - transparent back sheet module obtaining in average a gain of 20% in power output in comparison to a mono-facial operation of the module when penetration of reflecting light into the rear side of the module was inhibited (Table 3) [3].

TABLE 3. Outdoor measurements for bifacial module with different reflections from the rear side due to changed environment of the module [3].

	J_{sc} (A)	V_{oc} (V)	P_{mpp} (W)	*Rel. variation* (%)
No reflection	4.4	8.5	26.1	N/A
Reflection from grass	4.7	8.6	28.1	7.5
Reflecting surface of 90%	5.3	8.6	31.7	21.4

4. Conclusion

Within this work we identified and quantified the influence of several different back sheet configurations on IV- and QE measurements for bifacial solar cells and modules. A comparison of these results with those obtained for module laminates with different back sheets and glass rear sides will yield a basis for accurate performance predictions of bifacial photovoltaic outdoor installations.

An alternative for bifacial measurement and quick classification of bifacial solar cells is presented. It allows simultaneous front and rear illumination and gives a more comprehensive response for bifacial solar cell performance. This method is a quick and convenient alternative for classification of bifacial solar cells because describes the real operating mode of the cells, no other measurements up side down are needed and it can be extended to other types of bifacial cell configurations.

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